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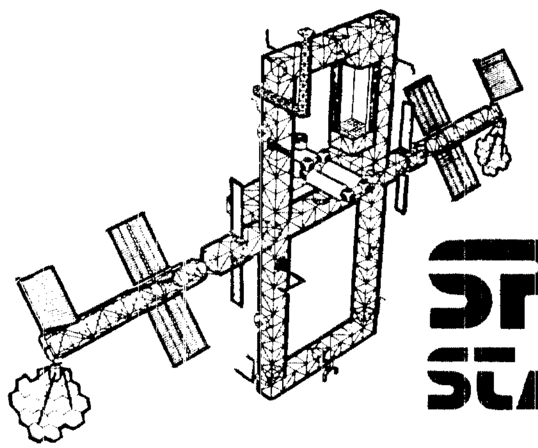

SPACE STATION

ACCOMMODATIONS FOR LIFE SCIENCES RESEARCH FACILITIES

Volume I - EXECUTIVE SUMMARY

Prepared For

NASA

GEORGE C. MARSHALL SPACE FLIGHT CENTER
ALABAMA 35812

BIOASTRONAUTICS
ASTRONAUTICS DIVISION
Lockheed Missiles & Space Company, Inc.
SUNNYVALE, CALIFORNIA

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FINAL REPORT - VOL. I EXECUTIVE SUMMARY

SPACE STATION ACCOMMODATIONS
FOR
LIFE SCIENCES RESEARCH FACILITIES

PHASE A CONCEPTUAL DESIGN & PROGRAMMATICS STUDIES
FOR MISSIONS SAAX0307, SAAX0302, AND THE TRANSITION FROM
SAAX0307 TO SAAX0302

MARCH 31, 1986

PREPARED UNDER CONTRACT NAS8-35472 CHANGE ORDERS 5 AND 7
FOR THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
ALABAMA 35812

LOCKHEED MISSILES & SPACE COMPANY, INC.
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FOREWORD

This report has been prepared under NASA Marshall Space Flight Center contract NAS8-35472. It provides the supplemental report pages called for by Change Orders 5 and 7 for the Final Report - Volume I Executive Summary.

Other reports in the series under contract NAS8-35472 include:

- Task 1. Parameter Analysis Data Package - LMSC/D914350 - August 1983
- Task 2. Tradeoff/Analysis Data Package - LMSC/D914366 - October 1983
- Task 3. Preliminary Conceptual Design Requirements Data Package - LMSC/D914369 - January 1984
- Final Review. July 1985
- Change Order 5 Special Report - LSRF Bioisolation Study - LMSC/D962181 - August 1985
- Final Report - Volume II. Study Results - Space Station Accommodations for Life Sciences Research Facilities - LMSC/F071319A- March 1986

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ACRONYMS & ABBREVIATIONS

AC	Alternating Current
ADU	Advanced Development Unit
AN	Applications Notice
AO	Announcement of Opportunity
ARC	Ames Research Center
BMVP	Bone, Muscle, Vestibular, Plant
Ca	Calcium
CELSS	Controlled Ecological Life Support System
CER	Cost Estimating Relationship
CFVP	Cardiovascular, Fluids, Vestibular, Plants
CO2	Carbon Dioxide
CV	Cardiovascular
DDT&E	Design, Development, Test, & Evaluation
ECLSS	Environmental Control and Life Support System
EDO	Engineering Development Unit
EKG	Electrocardiograph
EMC	Electromagnetic Capability
EMI	Electromagnetic Interference
EUE	Experiment Unique Equipment
EVA	Extra-Vehicular Activity
FC	Factor of Complexity
FOC	Follow-on (also Final) Orbital Configuration
FY	Fiscal Year
g	Earth Gravity
GPWS	General Purpose Work Station
GSFC	Goddard Space Flight Center
HRF	Human Research Facility
I/F	Interface
IOC	Initial Orbital Configuration (also Capability)
IVA	Intra-Vehicular Activity
JSC	Johnson Space Center
kg	Kilogram
KSC	Kennedy Space Center
kw	Kilowatt
LEMSCO	Lockheed Engineering and Management Services Company
LMSC	Lockheed Missiles & Space Company, Inc.
LSLE	Life Sciences Laboratory Equipment
LSRF	Life Sciences Research Facilities
m	Meter
MF	Muscle, Fluids
MFRP	Metabolism, Fluids, Reproduction, Plants
MIL-STD	Military Standard
MMS	Metabolic Measurement System
MPC	Mission Production Center
mps	Meter Per Second
MSFC	George C. Marshall Space Flight Center
NASA	National Aeronautics & Space Administration
O_2	Oxygen
OPS	Operations
ORU	Orbital Replacement Unit
PD	Preliminary Design
PI	Principle Investigator

ACRONYMS & ABBREVIATIONS

POCC	Payload Operations Control Center
RAHF	Research Animal Holding Facility
RFI	Radio Frequency Interference
RFP	Request For Proposal
RTOP	Research/Technology Operations Plan
SAAX0302	Science Mission of a Full Laboratory Module for Nonhuman Life Sciences
SAAX0307	Science Mission of a Half Laboratory Module for Nonhuman Life Sciences and Half for Human Life Sciences
SASP	Science and Applications Space Platform
SLM	Science Laboratory Module
SPF	Specific Pathogen Free
SS	Space Station
SSPE	Space Station Program Element
SSSC	Space Station Support Center
SSST	Space Station Systems Trainer
STS	Space Transportation System
UV	Ultra-Violet
VGRC	Variable Gravity Research Centrifuge
WBS	Work Breakdown Structure
Yr	Year
$K	Thousand of Dollars
$M	Millions of Dollars

SECTION 1
INTRODUCTION

This Executive Summary highlights Lockheed Missiles & Space Company's (LMSC's) conceptual designs and programmatics for a Space Station Nonhuman Life Sciences Research Facility (LSRF). Conceptual designs and programmatics encompass an Initial Orbital Capability (IOC) LSRF, a growth or Follow-on Orbital Capability (FOC), and the transitional process required to modify the IOC LSRF to the FOC LSRF. The IOC and FOC LSRFs correspond to missions SAAX0307 and SAAX0302 of the Space Station Mission Requirements Database. This summary includes an introduction and project results from subtasks 3.1 Requirements, 3.2 Concepts, and 3.3 Programmatics.

1.1 RELATED CONTRACT WORK

LMSC began LSRF studies for the George C. Marshall Space Flight Center (MSFC) in May 1983. Initial work focused on data base building plus a limited overall concept description. This work produced the following reports:

1. Orientation Briefing - June 8, 1983
2. Task 1 Parameter Analysis Data Package - LMSC/D914350 - August 3, 1983
3. Midterm Review - August 16, 1983
4. Task 2 Tradeoff Analysis Data Package - LMSC/D914366 - October 31, 1983
5. Task 3 Preliminary Conceptual Design Requirements Data Package - LMSC /D914369 - January 1984
6. Final Executive Review - May 1984

Subsequently, the contract was extended to conduct an in-depth tradeoff analysis dealing with isolation between crew and nonhuman specimens. This resulted in the report:

7. LSRF Bioisolation Study - LMSC/D962181 - August 1985

Finally the contract was amended to develop a "Preliminary Conceptual Design Requirements" data package which also included:

8. Study Midterm Review - May 3, 1985
9. Study Final Review - July 24, 1985

The work described in the background above was guided by MSFC under the technical direction of Dr. John D. Hilchey. Parallel studies were conducted by the Boeing Aerospace Company. Program direction was provided by the NASA Ames Research Center (ARC) on behalf of NASA headquaters Life Sciences Division. The ARC program manager is Roger Arno.

ARC also managed directly related efforts by McDonnell Douglas which focused first on a technology assessment of life sciences equipment and on describing the science protocols of ARC's strawman list of 54 representative expeirments. LMSC work has been based on this reference. McDonnell Douglas later conducted studies of research centrifuges and automation.

In addition NASA's Johnson Space Center (JSC) has been managing studies of a Human Research Facility (HRF). LMSC participated in this work as a subcontractor to Lockheed Engineering and Management Services Company (LEMSCO). The HRF would share facilities with the LSRF under the initial Space Station life sciences mission, SAAX 0307. Later, these missions would separate as the nonhuman LSRF would grow into its own module under mission SAAX 0302.

1.2 RELATIONSHIP TO SPACE STATION PROGRAM

The original work under this contract considered both a manned Space Station and an unmanned Science and Applications Space Platform (SASP) as the potential carriers for LSRF. As the project continued, NASA announced its intention to develop a permanently manned Space Station and the studies focused sharply on this carrier.

Under Phase B Definition and Preliminary Design studies, NASA Headquarters assigned the Goddard Space Flight Center (GSFC) to manage the outfitting of a Science Laboratory Module (SLM) for the station. Missions SAAX 0307 and SAAX 0302 were assigned to this module. LMSC is conducting one of the GSFC Phase B SLM studies under subcontract to RCA. Data or tradeoff results from that work have been taken into account under this LSRF study for MSFC. Likewise, LSRF results have influenced the direction of the GSFC work.

1.3 STUDY OBJECTIVES AND APPROACH

The study was conducted following the flow diagram shown in Fig. 1-1. The overall objective was to focus on conceptual design options and to recommend the best choice based on an evaluation against the science and engineering requirements. The approach to this objective included a brief review of science, an update of selected key trades from the earlier studies, and a layout of the engineering and mission design requirements structure for reference. In addition, four sample mission scenarios were established to test the concepts for their ability to be reconfigured on orbit and to transition to a complete LSRF module.

A second objective was to achieve an understanding of selected programmatics data associated with the conceptual design. The approach here was to develop a work breakdown structure for the LSRF on the basis of the entire job of converting a space station common module into a functioning lab. No effort was made to distinguish between the roles of the different NASA centers, eg, GSFC and MSFC or ARC, or the different NASA divisions, eg, Life Sciences (Code E) or Space Station (Code S).

Third objective was to define technology development requirements. All of the above fed into the final objective of preparing cost and schedule estimates and requirements relative to the overall space station schedule.

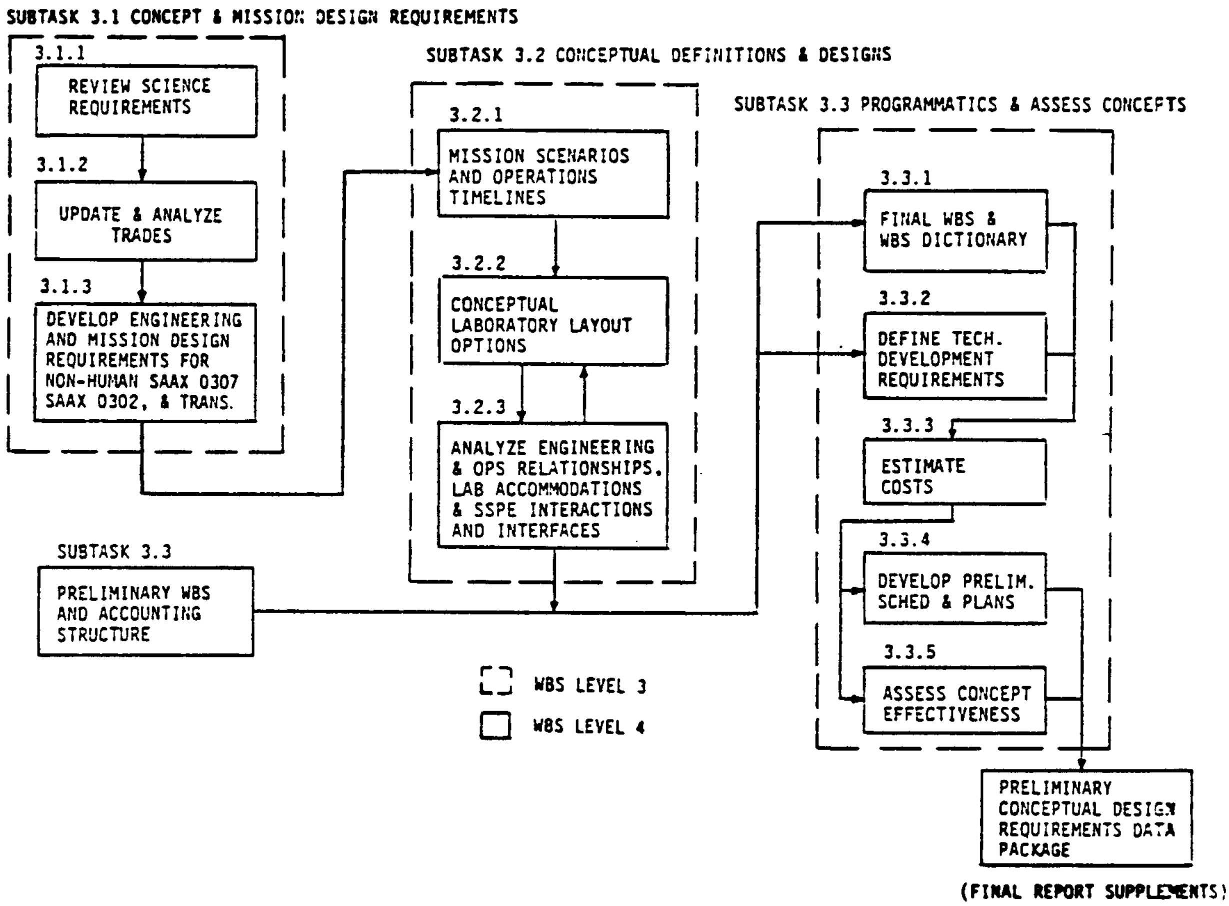

Figure 1-1 Study Flow Diagram

1.4 ASSUMPTIONS

The main assumptions of this project were:

- The LSRF would use the Space Station permanently manned concept as its carrier
- The LSRF housing would be the common module including its associated subsystems such as thermal, environmental control, power, and data management
- The missions of interest are US life sciences missions SAAX 0307 and 0302 of the Space Station Mission Requirements Data Base
- Strawman science experiments are the list of 54 from NASA ARC
- Prioritized equipment list is from LMSC's proposed study plan.

SECTION 2
REQUIREMENTS (TASK 3.1)

Science, mission, engineering, and operations considerations were addressed in the requirements analysis.

2.1 SCIENCE

Space Station Life Sciences Research Facilities (LSRFs) are needed to meet the objectives of the NASA Life Sciences program plan. The LSRF accommodates nonhuman specimens (plants and animals) to meet these objectives. The animal experiments typically planned would be coordinated with research on the human crew. The plant experiments will support the future development of CELSS (Controlled Ecological Life Support Systems), needed for extended lunar and orbital colonies and Mars missions, as well as gravitional biology.

LMSC has prioritized the ARC list of 54 strawman experiments (Table 2-1). The studies with highest priority are those which relate to understanding the biomedical problems of weightlessness. Those studies are also of great interest to basic biologists, because they address the questions of how gravity is sensed, how the sensor output is translated into tissue responses, and the series of physiological changes that result.

Understanding the process and designing countermeasures will require two approaches: collecting data from crewmembers and studying the mechanisms of the changes in animals. The importance of animal studies is that they allow more stringent procedures, including extensive use of tissue analyses. Some of the biomedical changes in weightlessness which are thought to be most important include decreases in bone mass and strength, decreases in muscle mass, cardiovascular changes, and altered vestibular function. Studies in those areas should be among the earliest on the Space Station.

TABLE 2-1 PRIORITIZED LIST OF STRAWMAN EXPERIMENTS

PROPOSED PRIORITY[1]	REFERENCE PRIORITY[2]	MDAC NO.[3]	LMSC NO.[4]	TITLE
1	B1	(A) BL 1a	1	Calcium/Bone Mineral balance on rats
2	B2	(A) ML 1a	6	Nitrogen balance and change in rat muscle structure
3	B3	(A) MB 1a	15	Metabolic balance changes in rats
4	B4	(W) MB 4	19	Respiratory quotient (O_2/CO_2) changes in rats
5	B5	(W) BL 4	5	Calcium/Mineral balance in rats using nonradioactive tracers
6	B7	(A) FE 1a	12	Fluid/electrolyte changes in rats
7	L1	(A) BL 1b	2	Calcium/Mineral balance on squirrel monkeys
8	L2	(A) ML 1b	7	Nitrogen balance and change in squirrel monkey muscle structure
9	B16	(A) VP 1	23	Vestibular organ structural change in rats
10	B17	(A) VP 2a	24	Vestibular system operation changes in rats
11	L5	(A) VP 2b	25	Vestibular system function changes in squirrel monkeys
12	B8(L7)	(A) PC 1	44	Plant development following sprouting
13	B9(L8)	(A) PC 3	46	Plant growth in 0g
14	B10(L9)	(W) PC 8	51	Multiple generation plant growth
15	B11(L10)	(W) PC 9	52	Gas balance on plants
16	B12(L11)	(A) PC 2	45	Gravitational strength and orientation effects on plant development
17	B13(L12)	(W) PC 6	49	Weightlessness effects on microscopic plants
18	B14(L13)	(W) PC 7	50	Geotropism threshold experiments
19	B15(L14)	(A) PC 4	47	Prototype CELSS plant unit
20	L15	(A) FE 1b	13	Fluid/electrolyte changes in squirrel monkeys
21	L3	(A) CV 1	9	Cardiovascular function changes in restrained <u>Rhesus</u> monkeys
22	L4	(W) CV 2	10	Cardiovascular system changes in restrained <u>Rhesus</u> monkeys
23	L6	(A) VP 2c	26	Vestibular system function changes in <u>Rhesus</u> monkeys
24	L16	(W) FE 2	14	Fluid shifts in restrained Rhesus monkeys
25	L17	(A) MB 1b	16	Metabolic balance in squirrel monkeys
26	L18	(W) MB 5	20	Respiratory quotient (O_2/CO_2) in squirrel monkeys
27	L19	(W) MB 6	21	Energy expenditure/CO_2 production in squirrel monkeys
28	L20	(W) MB 7	22	Time-dependent glucose metabolism changes in squirrel monkeys
29	L21	(A) VP 2d	27	Vestibular system operation changes in cats
30	L22	(A) VP 2e	28	Vestibular system function changes in pigeons
31	L23	(A) VP 2f	29	Vestibular system function changes in frogs
32	L24	(A) VP 2g	30	Vestibular system function changes in goldfish
33	L25	(W) VP 3	31	Vestibular system function changes in squirrel monkeys
34	B18	(W) BL 2	3	Bone development in early stages of rat fetuses
35	B19	(W) BL 3	4	Bone development in early pregnancy over multiple rat generations
36	B20	(W) CV 3	11	Development of rat CV reflexes, sensors
37	B21	(A) RD 3	36	Multigeneration changes in rat reprod. behavior and develop.
38	B22	(W) RD 5	38	Rat development
39	B23	(W) RD 6	39	Rat post natal development at 19 days
40	B24	(A) RD 1	32	Multiple generation mouse development
41	B25	(A) RD 2c	35	Mouse development
42	B26	(W) RD 7	40	Rat development cycle following birth in 0g
43	B27	(W) RD 8	41	Determine gravity threshold for development changes in rats
44	B28	(A) RD 2b	34	Early development in chickens
45	B29	(A) RD 4	37	Chicken development and hatching
46	B30	(A) RD 2a	33	Early development in frogs
47	B31	(W) MB 2	17	Changes in mouse metabolism
48	B32	(W) MB 3	18	Recovery in mouse metabolism to 1g
49	B33(L26)	(A) PC 5	48	Prototype algae CELSS unit
50	B34(L27)	(W) PC 10	53	Plant lignification
51	B35(L28)	(W) PC 11	54	Plant growth rate changes due to light/dark cycle
53	B36	(A) RB 1	42	Passive radiation dosage in mice
53	B37	(A) RB 2	43	Passive radiation dosage in mice
54	B6	(W) ML 2	8	Nitrogen balance and rat muscle structure changes with tracers

[1] Proposed priority: LMSC recommended starting point for use of experiments in trade studies based on a blending of reference priorities

[2] Reference priority: Prioritized list of experiments specified in Hilchey memorandum dated October 12, 1983
B=Boeing; L=Lockheed

[3] MDAC No: (A) Ames Research Center report "Life Sciences Research and the Science and Applications Space Platform"
(W) "Experiments Derived from the 1982 Life Science Workshops" by Heinrich (ARC)

PC= plant growth | RB= radiation
BL= bone loss | RD= animal development
CV= cardiovascular | VP= vestibular system
FE= fluid/electrolyte | MB= metabolic balance
ML= muscle loss

[4] LMSC No.: Lockheed experiment numerical listing specified in Appendix 1 - Parameter Analysis Data Package - Life Sciences Research Facility System analysis Study

Most life sciences experiments will need to be repeated many times. Repetition of an experiment unchanged would be for the purpose of confirming the results. In most cases an experiment would be modified when repeated, to extend the information obtained the previous time. Some experiments may be repeated one or more times during a 90-day mission. Other studies will require holding specimens on the station for multiples of 90 days; examples are long-term radiation effects, and multi-generation studies on mammals.

Data sheets were developed in earlier work and updated for all of the 54 experiments in the list. The number-one priority experiment, BL1A Bone Loss in Rats, is described in the data sheet in Fig. 2-1. The experiment data are used in defining core equipment (basic items generic to life sciences research) as well as experiment unique equipment which must be accommodated in the LSRF design approach.

2.2 MISSION

There are no requirements for particular orbital altitude or inclination, viewing angles, attached payloads, or EVA servicing (at IOC or near-term). Life Sciences missions do have special requirements related to the use of live specimens, however. These include:

- o <u>ECLSS.</u> Animal and plant holding facilities with bioisolation from the surrounding laboratory and temperature and humidity controls which are more accurate than the laboratory module as a whole.
- o <u>Work Stations.</u> Closed or laminar-flow workbench(es) for carrying out research procedures on plants and animals without danger of contamination of the specimens or lab. Procedures include use of chemicals, mass determinations, examination, testing, transfer, dissection, analysis, and preservation of specimens.
- o <u>Storage.</u> Refrigerators and freezers to maintain unstable chemicals and preserve biological specimens for ground analysis. Because many of the constituents of interest are extremely labile, cryogenic temperatures are necessary for some samples.

Experiment No. BL1A

EXPERIMENT TITLE: BONE LOSS IN RATS
OBJECTIVE: Determine Effects of Microgravity on Calcium/Mineral Balance in Rats; Radiology, Histology, Biomechanics, Osteoblast Differentiation, Tooth Eruption Rate, Joints, Calcium Metabolism.

SPECIES: Rat, Mature Males	SIZE: 400-600 g	DURATION: 90 Days
SUGGESTED NUMBER: 90	STATION G LEVEL	45 (50%)
	FRACT G (Centrifuge)	
	1 G (Centrifuge)	45 (50%)

TASK	FREQUENCY	POTENTIAL FOR AUTOMATION
Vivarium: Urine/Feces Sample	2 days/week	X
RAHF/VGRF Maintenance	Every 7 days	X
Support Lab:		
Weigh Specimens	Every 7 days	
Blood Samples/Preserve	Every 7 days	
Sacrifice/Dissect/Preserve	6 each at 2, 10, 20, 30, 50, 85 days	
X-Ray	Every 14 days	
Bone thin sections & U-V Microscopy	At sacrifice	

EQUIPMENT - VIVARIUM	DATA
RAHF/Rodent Environment, Food & Water Consumption, Activity	DL
VGRF/Rodent Environment, Food & Water Consumption, Activity	DL
Solid & Liquid Waste Storage	-
Hand Wash Facility Cage Cleaning Facility	-

EQUIPMENT - SUPPORT LAB		DATA
Surgical Workbench	Chemical Storage (opt)	-
Mass Measurement Device (Small)	Dry Storage (opt)	-
Sacrifice Kit	Freeze Dryer (opt)	-
Blood Collection Kit	Thin Section Saw	-
Laboratory Centrifuge		-
Wet Trash Storage	X-Ray & Developer	
	X-Ray Digitizer	-
Freezer		-
Quick Freeze Unit		-
Hand Wash Facility	Binoc. Microscope	-

SAMPLE STORAGE & RETURN NO./TYPE SAMPLES	FREEZE DRY	REFRIG.	FREEZE	FIX
Bone			X	X (opt)
Feces			X	
Urine			X	
Blood			X	
Carcasses	X (opt)		X	X (opt)

SPECIMEN RETURN/SACRIFICE
20% (18) returned live
80% (72) returned sacrificed

SPECIAL ENVIRONMENTAL REQUIREMENTS (IF ANY)

None

Figure 2-1 Bone Loss Experiment Data Sheet

- <u>Laboratory Equipment.</u> Analytical tools are needed for testing, injecting, handling, and dissecting specimens; for blood and urine collection and analysis; and for specialized studies in electrophysiology, cardiology, vestibular activity, radiology, and other areas.

- <u>Artificial Gravity.</u> A large-diameter centrifuge to apply gravity forces to groups of animals and plants for up to 90 days. Some specimens will serve as 1g ("normal") controls for similar specimens maintained at 0g. The centrifuge also must provide fractional g and hyper-g to study the thresholds at which physiologycal changes occur or can be prevented.

Because each 90-day mission will begin with the supply of new specimens and some equipment items, all missions may be considered as reconfigurations. Several reconfiguration scenarios were developed as examples of logical groupings of experiments.

Operationally, transitioning from the combined laboratory (SAAX 0307) to the dedicated plant-animal lab (SAAX0302) should minimize equipment changeout. It is recommended that the combined lab grow to the dedicated animal-plant lab leaving the centrifuge in place. The newly-launched module then would become a human research facility.

2.3 ENGINEERING

The LSRF is a multi-mission facility outfitted with general purpose subsystems and equipment items analogous to the Spacelab Life Sciences Laboratory Equipment (LSLE). The lab is at the disposal of various users, each with a particular mission. The LSRF also interfaces with common module subsystems (ECLSS, power distribution, data management, etc.) that are in support of the primary equipment complement and the users.

Bioisolation was identified as a key driver, perhaps the dominant issue in LSRF design. Because of its importance, the bioisolation issues were the main focus of a separately reported contract extension study, Change Order #5.

The study concluded that using specific pathogen free (SPF) animals is the preferred approach to specimen selection and that cage-level isolation is both much more effective a measure than the use of module partitions, and is much less disruptive of routine activity. Figure 2-2 shows an overview of the different vivarium subsystems that are interlinked in the bioisolation tradeoff analyses.

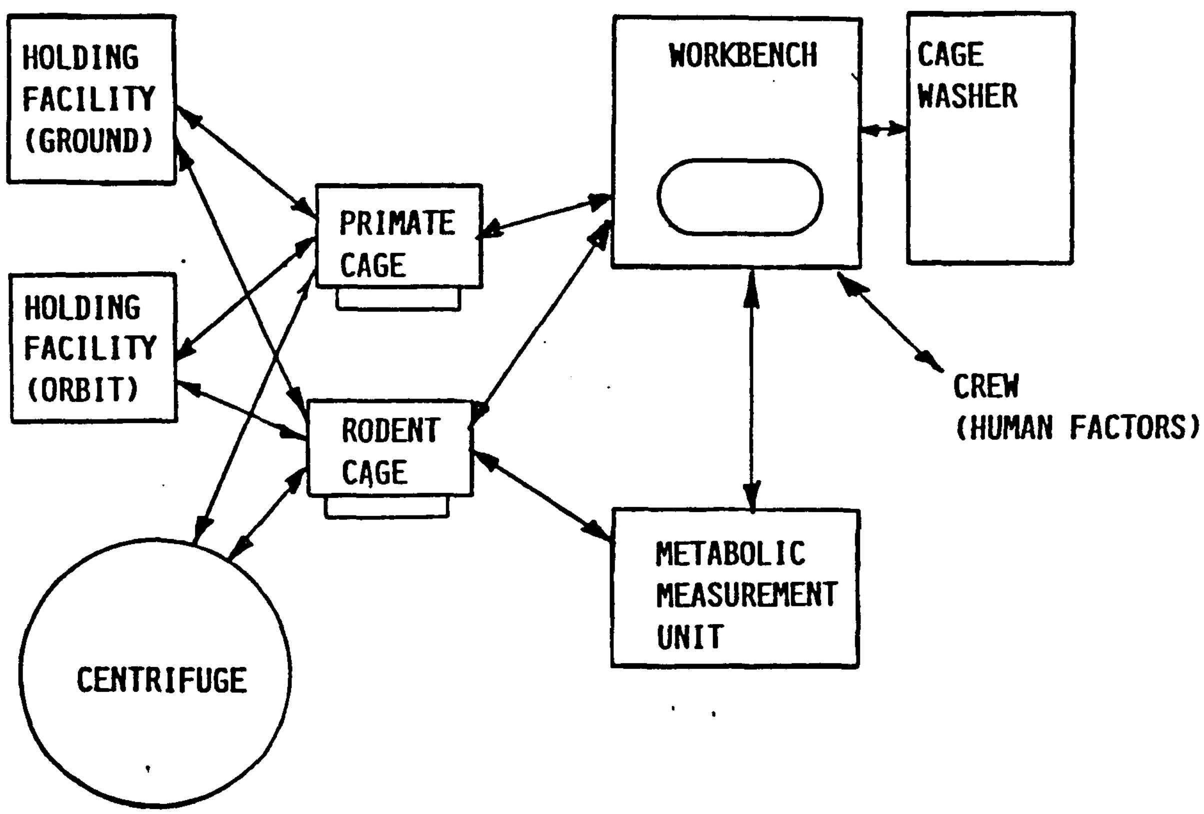

Figure 2-2 Vivarium Bioisolation Interface

Other tradeoffs have been reported in earlier documents. Important issues which have been taken into account in the conceptual design include:

- Equipment Sharing & Commonality
- Vivarium location (in lab vs. logistics module vs. special module)
- Centrifuge location and architecture
- Waste storage
- Logistics (animal resupply)

2.4 OPERATIONS

LSRF reconfiguration scenarios and internal layouts are the primary drivers influencing lab operations and support facilities. Elements in the operational sequence include pre-mission, on-orbit, post-mission, and ground-based facility support activities. These activities must be fully integrated to handle all experiments in various phases of the operational sequence at anytime. Figure 2-3 provides an overview of the operational sequence for a typical LSRF mission.

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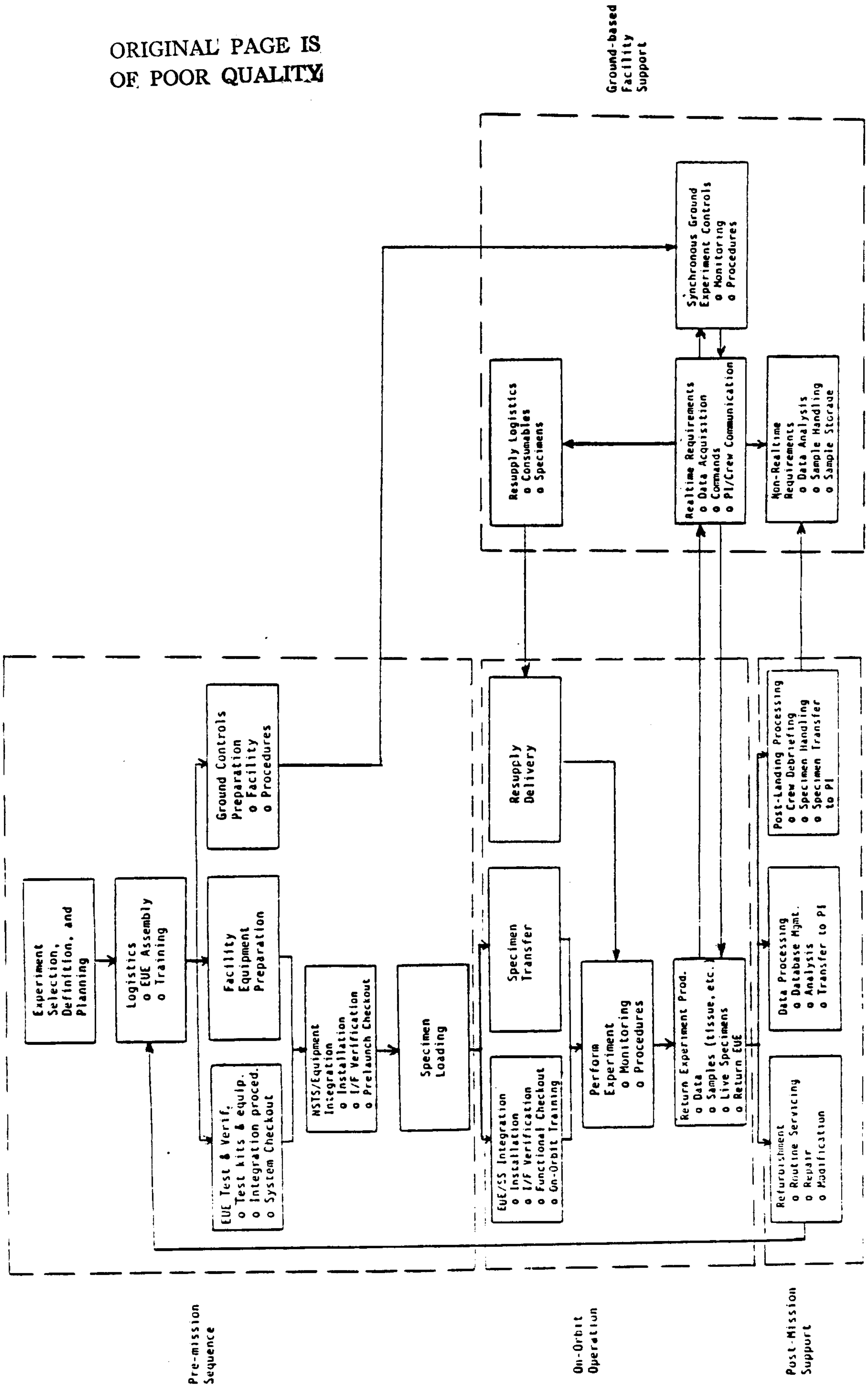


Figure 2-3 Engineering & Operational Relationships, Interactions, & Interfaces

SECTION 3
CONCEPTUAL DEFINITION AND DESIGNS (TASK 3.2)

This section overviews LSRF layouts and subsystem studies.

3.1 LAYOUTS

Eight module arrangement conceptual layouts were developed (see Table 3-1) with nonhuman equipment outfitting volumes equal to either a half or a full module. The half-module concepts are designed to be combined with either hab module equipment such as the Health Maintenance Facility or other lab functions such as materials technology. Module length is constant at 13.7 meters. The options are based on the use of a 2.75m diameter side-mounted centrifuge or a 3.75m full-module diameter double rotor centrifuge combined with either a horizontal or vertical layout. Prioritized equipment lists developed by NASA Ames Research Center were used in equipping the lab options (see Tables 3-2 and 3-3).

TABLE 3-1 LAYOUT OPTIONS CONSIDERED

Half Module (SAAX0307)	Horizontal	Small Centrifuge	Figs. 4-1 and 4-2	#1
		Large Centrifuge	Figs. 4-3 and 4-4	#2
	Vertical	Small Centrifuge	Figs. 4-5 and 4-6	#3
		Large Centrifuge	Figs. 4-7 and 4-8	#4
Full Module (SAAX0302)	Horizontal	Small Centrifuge	Figs. 4-9 and 4-10	#5
		Large Centrifuge	Figs. 4-11 and 4-12	#6
	Vertical	Small Centrifuge	Figs. 4-13 and 4-14	#7
		Minilab Option	Figs. 4-15 and 4-16	#7A
		Large Centrifuge	Figs. 4-17 and 4-18	#8

The Space Station Common Module is the carrier for the LSRF layouts. It provides basic services such as environmental control, thermal control, power distribution, and a link to the communications and data systems.

TABLE 3-2 RESEARCH EQUIPMENT FOR NONHUMAN LIFE SCIENCES: FIRST HALF-MODULE

Item	Quantity	Unit characteristics Weight, kg	Volume, liters	Power, W
0-g standard habitat, ECLS[a] (24 rat equiv.)	1	450	1800	500
0-g breeding habitat, ECLS (12 rat equiv.)		250	1000	250
0-g metabolic habitat, ECLS (4 rat equiv.)		200	500	200
1-g centrifuge, controls, ECLS (18 rat)		1000	4000	500
Plant growth facility (100 liter capacity)	1	250	1000	1500
Multipurpose workbench	1	350	2000	500
Animal restraint/transport device	1	20	100	
Refrigerator (-20°C) 30-liter capacity	2	100	300	200
Freezer (-70°C), 20-liter capacity	1	100	300	300
Cryogenic freezer (-195°C)		100	400	500
Computer/data display/data storage	1	100	500	400
Video camera, recorder, monitor, tape	1	50	200	200
Animal physiological monitoring system	1	20	100	50
Biomedical recorder/plotter	1	30	100	150
Autoclave/drying oven		100	200	500
Incubator/culture growth system	1	100	200	100
Laboratory refrigerator centrifuge	1	30	100	450
Small mass measuring device	1	20	50	20
Dissecting or binocular microscope	1	10	20	200
Gas chromatograph	1	25	150	100
Mass spectrometer	1	40	100	200
Echocardiograph		100	200	450
Spectrophotometer	1	40	100	300
Ultrasound		100	200	600
pH/ion analyzer	1	10	5	10
Radiation dosimeter	1	5	5	15
Hematology, fluid handling kit	1	10	20	100
Surgery/dissection kit, guillotine	1	15	10	
Plant tool kit or veterinary kit (ea)	2	20	10	100
Hand wash facility	1	100	500	375
Gown change room, partitions	1	1000	3000	
Waste handling system, freeze dryer	1	100	300	300
Cage cleaning system	1	100	250	250
Secondary structure, grips, restraints	1	200	50	
Dynamic environment/accelerometer system	1	40	100	20
Environmental monitoring and control	1	200	500	3000
Lighting system and controls	1	50	50	300
Storage allowance	1	25	1000	
TOTALS (unit characteristics × quantity)		3730	13230	9940

[a]ECLS = environmental control and life support

TABLE 3-3 RESEARCH EQUIPMENT FOR NONHUMAN LIFE SCIENCES: SECOND HALF-MODULE

Item	Quantity	Unit characteristics Weight, kg	Volume, liters	Power, W
0-g standard habitat, ECLS[a] (24 rat equiv.)	1	450	1800	500
0-g breeding habitat, ECLS (12 rat equiv.)	1	250	1000	250
0-g metabolic habitat, ECLS (4 rat equiv.)	1	200	500	200
1-g centrifuge, controls, ECLS (18 rat)	1	1000	4000	500
Plant growth facility (100 liter capacity)	1	250	1000	1500
Multipurpose workbench		350	2000	500
Animal restraint/transport device	1	20	100	
Refrigerator (-20°C) 30-liter capacity	2	100	300	200
Freezer (-70°C), 20-liter capacity	1	100	300	300
Cryogenic freezer (-195°C)	1	100	400	500
Computer/data display/data storage		100	500	400
Video camera, recorder, monitor, tape	1	50	200	200
Animal physiological monitoring system	1	20	100	50
Biomedical recorder/plotter	1	30	100	150
Autoclave/drying oven	1	100	200	500
Incubator/culture growth system		100	200	100
Laboratory refrigerator centrifuge	1	30	100	450
Small mass measuring device	1	20	50	20
Dissecting or binocular microscope	1	10	20	200
Gas chromatograph		25	150	100
Mass spectrometer		40	100	200
Echocardiograph	1	100	200	450
Spectrophotometer		40	100	300
Ultrasound	1	100	200	600
pH/ion analyzer		10	5	10
Radiation dosimeter		5	5	15
Hematology, fluid handling kit	1	10	20	100
Surgery/dissection kit, guillotine	1	15	10	
Plant tool kit or veterinary kit (ea)	2	20	10	100
Hand wash facility		100	500	375
Gown change room, partitions		1000	3000	
Waste handling system, freeze dryer		100	300	300
Cage cleaning system		100	250	250
Secondary structure, grips, restraints	1	200	50	
Dynamic environment/accelerometer system		40	100	20
Environmental monitoring and control	1	200	500	3000
Lighting system and controls	1	50	50	300
Storage allowance	1	25	1000	
TOTALS (unit characteristics × quantity)		3570	12520	10370

[a]ECLS = environmental control and life support

Internal layout options directly influence the number and types of experiments and the ability of the crew to complete the experiments that are flown. Vertical arrangements are preferred because with similar equipment volumes vertical arrangements are simpler and more uniform with a greater degree of commonality possible. Vertical module packaging also is more simply arranged, allowing more crew working space and higher packaging efficiency.

Thus, for the half-module SAAX0307 mission, option #4 was determined to be the best and for the full-module SAAX0302, option #8 was the best. The former is shown in Figs. 3-1 and 3-2 and the latter in Figs. 3-3 and 3-4.

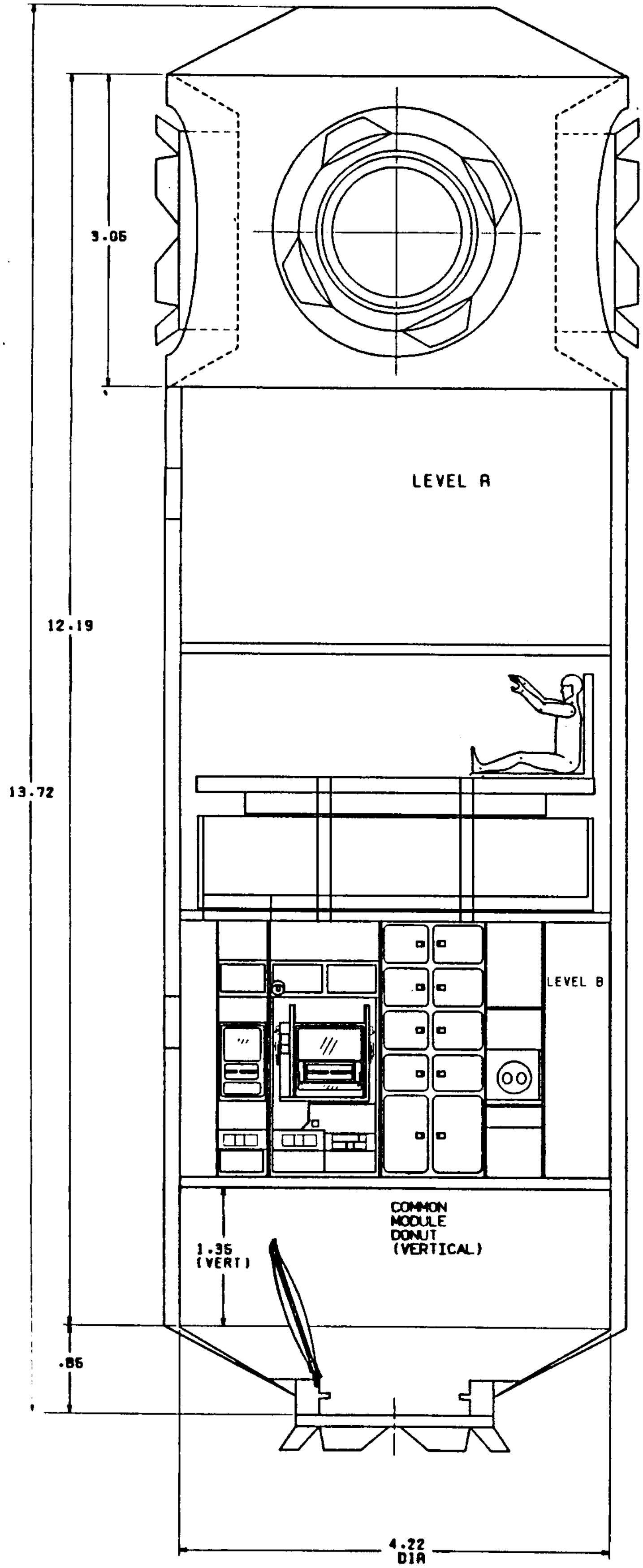


Figure 3-1 Half Lab Concept With Large Dual-Rotor Centrifuge (Option #4)

RACK NUMBER	RACK VOLUME (CUBIC M)	USER DESIGNATION	EQUIPMENT
1	2	NON-HUMAN	GENERAL PURPOSE WORK STATION (#11), DISSECTION KIT(*124), SPECTROPHOTOMETER (*206), MASS SPEC/ GAS ANALYZER (*163), ANIMAL MONITORING (*203).
2	2	NON-HUMAN	STORAGE.
3	1	NON-HUMAN	HAND WASHER (#100).
4	1	NON-HUMAN	INCUBATOR CO2(*202), EGG INCUBATOR (*76), CELSS (*90), FREEZER(*45A),LABORATORY CENTRIFUGE (*28).
5	1	NON-HUMAN	PLANT RESEARCH FACILITY (*81).
6	2	1 H, 1 N-H	DATA SYSTEM (*33-36), COMPUTER (*51), STRIP CHART RECORDER (*162), MICROPROCESSOR (*209), VIDEO CAMERA AND RECORDER (*141).
7	2	NON-HUMAN	CAGE WASHER (*98), SPECIMEN FOOD AND WATER (*96,97), STORAGE.
8	1	NON-HUMAN	RODENT STANDARD HOLDING FACILITY (#52A).
9	1	NON-HUMAN	STORAGE, PH/ION ANALYZER (#208), OSCILLOSCOPE (*207), MICROSCOPES (*).
10	1	NON-HUMAN	RODENT STANDARD HOLDING FACILITY (#52).
XX	14	7 H, 7 N-H	3.75 METER DIAMETER SPECIMEN RESEARCH CENTRIFUGE
11	1	.5 H, .5 NH	CENTRIFUGE CONTROLS (*63), STORAGE.
12	1	.5 H, .5N-H	REFRIGERATOR/FREEZERS (*44,45), ENVIRONMENTAL MONITOR (*142), PHYSIOLOGICAL AMPLIFIER (*143), DOSIMETER (*125), SMALL MASS MEASUREMENT (*112).
	14 2	NON-HUMAN HUMAN	TOTAL VOLUME

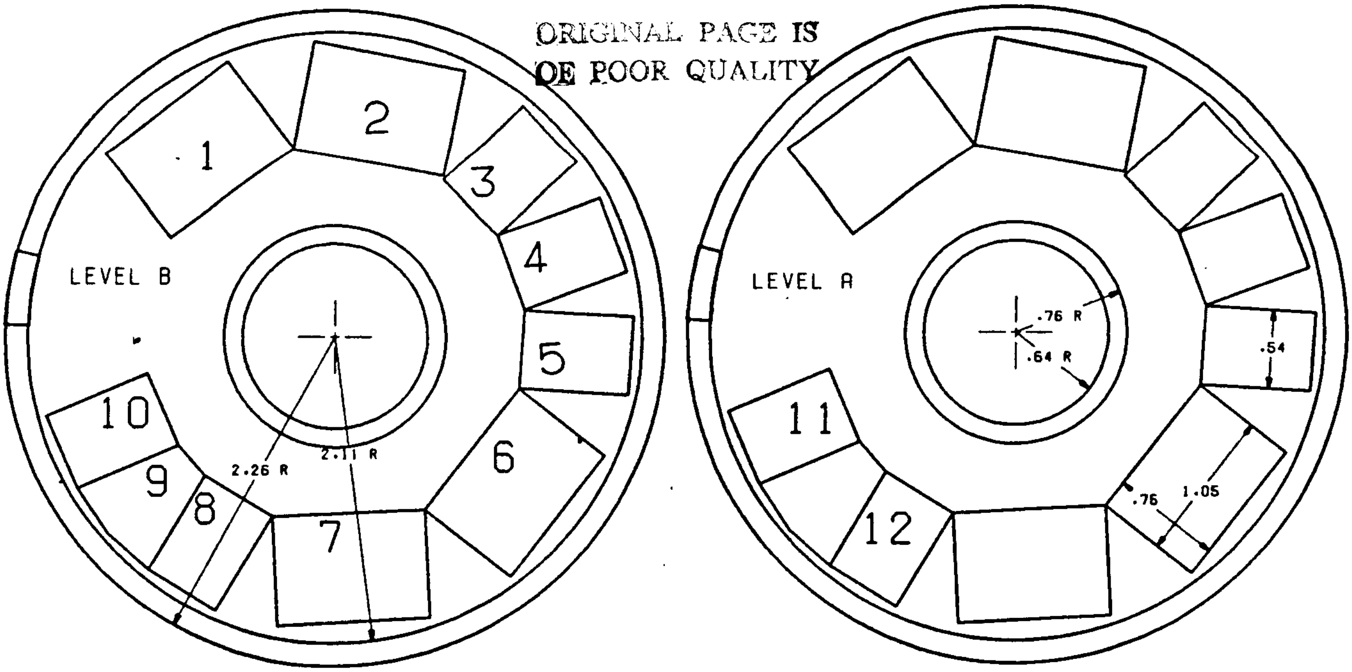


Figure 3-2 Equipment and Rack Location for Option #4

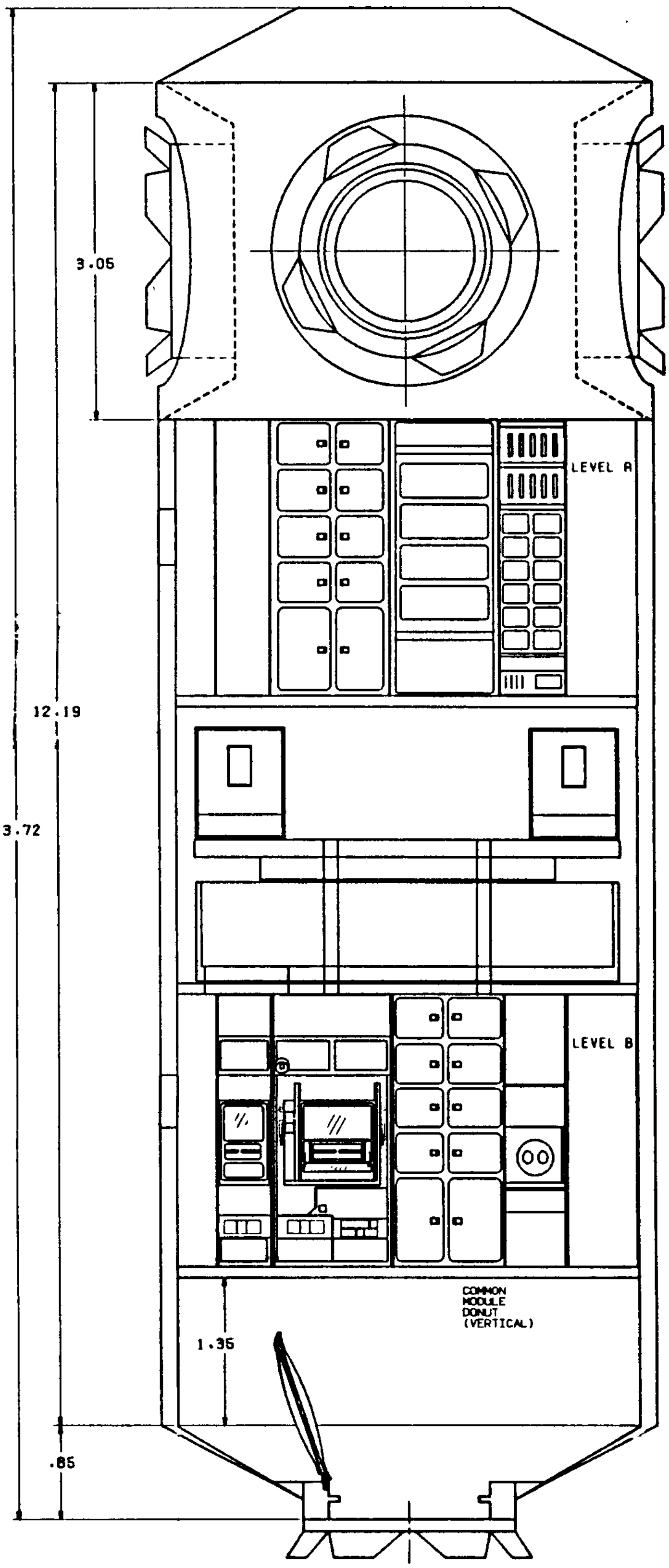
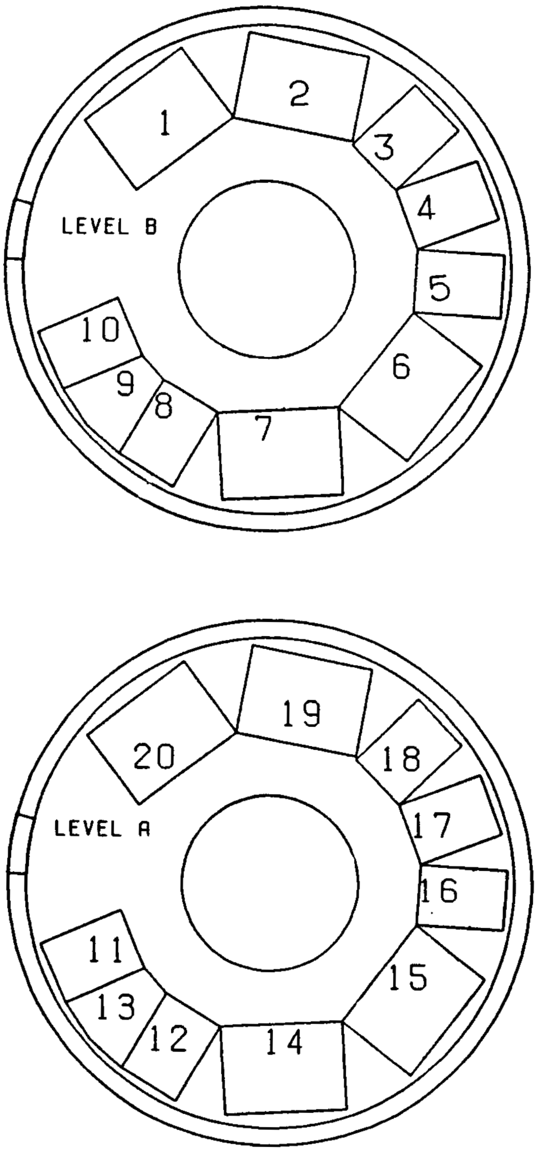


Figure 3-3 Full Lab Concept With Large Centrifuge (Option #8)



RACK NUMBER	RACK VOLUME (CUBIC M)	EQUIPMENT
1	2	GENERAL PURPOSE WORK STATION (#11). DISSECTION KIT(*124). SPECTROPHOTOMETER (*206). MASS SPEC/GAS ANALYZER (*163). ANIMAL MONITORING (*203).
2	2	STORAGE.
3	1	HAND WASHER (#100).
4	1	INCUBATOR CO_2(*202). EGG INCUBATOR (*76). CELSS (*90). FREEZER(*45A).LABORATORY CENTRIFUGE (*28).
5	1	PLANT RESEARCH FACILITY (*81).
6	2	DATA SYSTEM (*33-36). COMPUTER (*51). STRIP CHART RECORDER (*162). MICROPROCESSOR (*209). VIDEO CAMERA AND RECORDER (*141).
7	2	CAGE WASHER (*98). SPECIMEN FOOD AND WATER (*96,97). STORAGE.
8	1	RODENT STANDARD HOLDING FACILITY (#52A).
9	1	STORAGE, PH/ION ANALYZER (#208). OSCILLOSCOPE (*207). MICROSCOPES (*). PRIMATE KIT (*205).
10	1	RODENT STANDARD HOLDING FACILITY (#52B).
XX	14	3.75 METER DIAMETER SPECIMEN RESEARCH CENTRIFUGE.
11	1	CENTRIFUGE CONTROLS (*63). STORAGE.
12	1	PLANT RESEARCH FACILITY (*81A).
13	1	REFRIGERATOR/FREEZER (*44A). ENVIRONMENTAL MONITOR (*142). PHYSIOLOGICAL AMPLIFIER (*134). DOSIMETER (*125). SMALL MASS MEASUREMENT (*112).
14	2	STORAGE.
15	2	RODENT BREEDING HOLDING FACILITY (*153).
16	1	REFRIGERATOR/FREEZERS(*44B.45B). SPECIMEN FOOD AND WATER(*96A.97A).
17	1	METABOLIC HOLDING FACILITY.
18	1	RODENT STANDARD HOLDING FACILITY (*52C).
19	2	LARGE PRIMATE HOLDING FACILITY (*58). STORAGE.
20	2	STORAGE.
	42	TOTAL VOLUME

Figure 3-4 Equipment Identification by Rack Location for Option #8

3.2 SUBSYSTEMS

The common module contains secondary structure and network distribution system for life support, data management, electrical power distribution and final conditioning, thermal management, and communications. Internal LSRF outfitting must be compatible with external structural features to facilitate: equipment/specimens/supplies transfer from STS orbiter into the lab, earth viewing, power, ECLSS, thermal and data management interfaces with the logistics module, and safety egress requirements for crew in emergency situations.

LSRF internal arrangements also must be compatible with common module interior characteristics to ensure proper interface during ground and on-orbit assembly activities.

The equipment mounting system is the means for integrating the laboratory elements into laboratory arrangements. To complete this integration, the mounting system concepts (racks) investigated by LMSC were designed to provide the following:

- Interfaces to support operation of common laboratory equipment and user equipment
- Structural integrity for applicable loads and environments
- Easy change-out of Orbital Replacement Units (ORUs)
- Accessibility for maintenance, service, and repair of laboratory equipment and of module elements
- Commonality with other Space Station elements

SECTION 4
PROGRAMMATICS (TASK 3.3)

The elements of programmatics studied included the WBS, technology development, costing, and planning.

4.1 WORK BREAKDOWN STRUCTURE

The WBS was updated from the December 1984 report to correspond to the Space Station RFP. WBS elements 1.0 through 7.0 address common module end items from Work Package 01 that must be enhanced to achieve an operational LSRF by IOC. Items 8.0 through 21.0 address LSRF operational activities and associated hardware required for IOC. The WBS was developed to level 5 and a definition for each WBS level 4 and 5 element prepared. The top level WBS (to level 4) is shown in Fig. 4-1.

4.2 TECHNOLOGY DEVELOPMENT

Technology development activities play an integral part in the development of a fully operational LSRF that is compatible with other Space Station elements. LMSC developed detailed discussions of a Variable Gravity Research Centrifuge (VGRC), Metabolic Measurement System (MMS), and a Cage Washer including specific areas requiring additional study and advances required to develop the technology fully. These technology development areas were selected for study after an evaluation of experimental protocols and equipment lists expected to be representative of LSRF work.

A concept of the large dual-rotor centrifuge with center pass-through, magnetic bearings, automated servicing, and human research capability is shown in Fig. 4-2.

4.3 COST ESTIMATES

The cost estimates developed address design, development, test, and evaluation (DDT&E) and operations costs for IOC (SAAX0307) and FOC

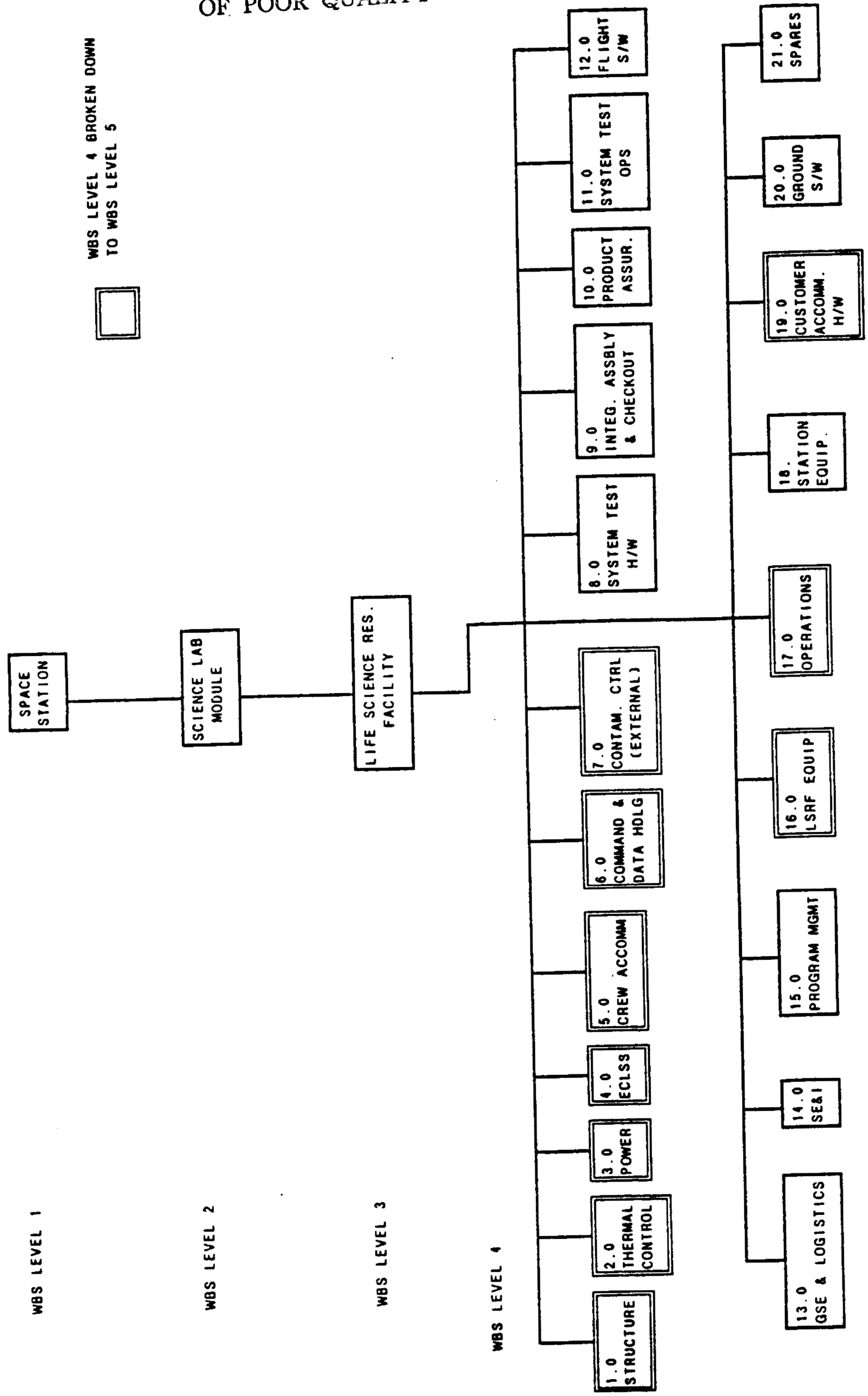


Figure 4-1 Work Breakdown Structure to Level 4

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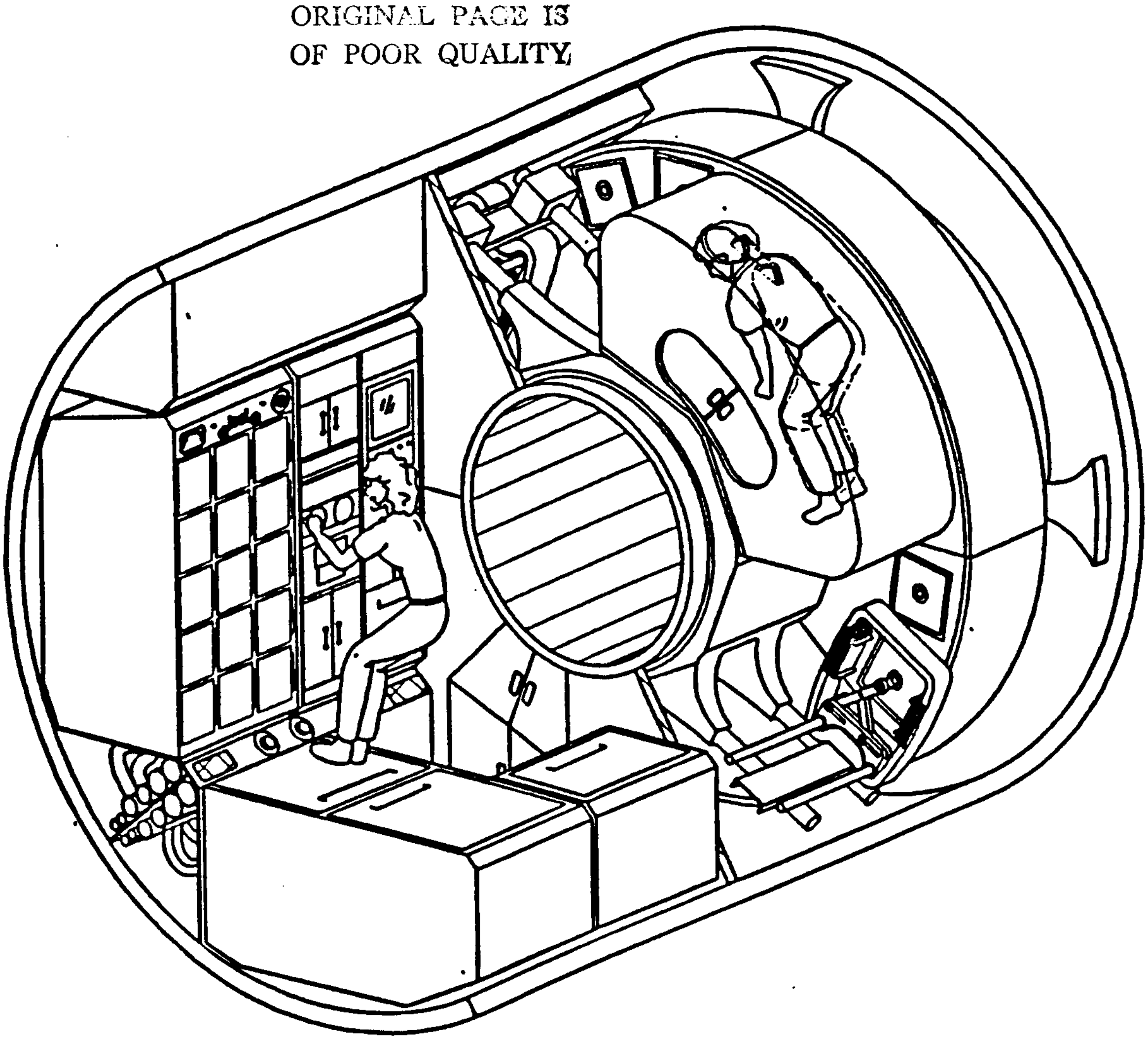

Figure 4-2 3.75 Meter Centrifuge With Servicing Rotor in Module End

(SAAX0302). The SAAX0307 represents the LSRF portion or one-half of a Science Laboratory Module (SLM) at IOC. The SAAX0302 estimate is for a dedicated animal-plant vivarium lab which becomes operational two years after IOC. Assumptions and groundrules used to generate cost estimates include the following:

- o Costs are in constant year FY 1987 million dollars
- o Estimates are for a 13.7m module in a racetrack configuration
- o Development approach is protoflight program
- o Costs for WBS functional elements and non-flight hardware are generated by applying factors arrived at by engineering judgement
- o Weights for life science flight hardware are based on earlier LSRF work, adjusted in some cases to reflect current thinking

Cost Estimating Relationships (CERs) for equipment items are computed on the basis of weight, a complexity factor, and state of development. Cost adjustments within each CER can be made by assigning a complexity factor (FC) for each equipment item. The normal factor is unity. An equipment item deemed to be lower or higher in complexity should be assigned a complexity factor lower or higher than unity.

Equipment costs also can be adjusted relative to development status of the item. For example, an item that has already been developed or exists as flight qualified hardware will not be charged for full development costs. Each equipment item, therefore, was assigned a number that reflected its development status as it will exist at the start of Phase C/D.

Funding profiles for LSRF Missions SAAX0307 and SAAX0302 were constructed to evaluate funding requirements from program initiation through first launch. The profiles (Fig. 4-3) are generated based upon a seven-year program. It was assumed that program start commenced in FY 1986 and that the program ends with a launch in March 1993.

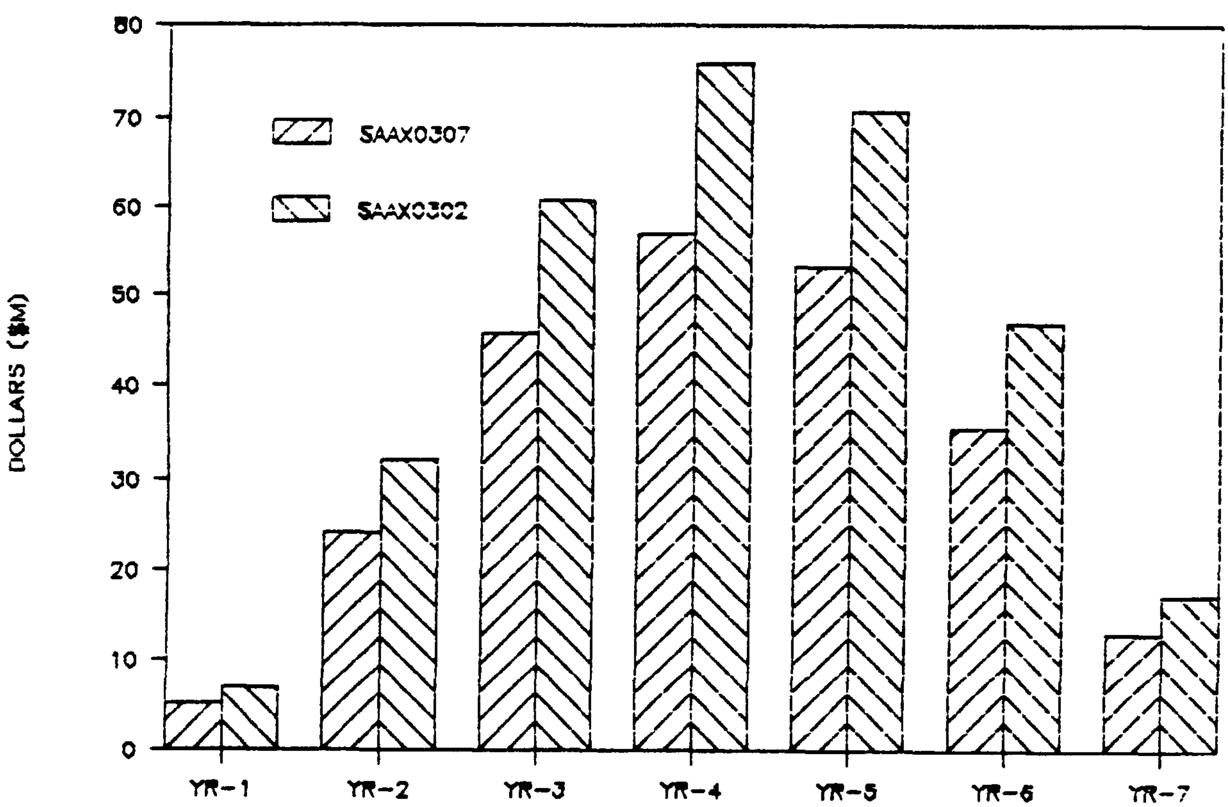

Figure 4-3 Funding Profiles

Annual operations costs were estimated for pre-launch, on-orbit, and post-return operational activities involving the LSRF portion of the combined lab (SAAX0307) and the dedicated animal-plant vivarium and lab (SAAX0302). These are shown in Table 4-1.

TABLE 4-1 OPERATING COSTS FOR SAAX0302 AND SAAX0307

WBS ELEMENT TITLE	COST ($M) SAAX0307	SAAX0302
Training	1.16	2.31
Logistics	18.57	37.14
Airborne Support Equipment	0.14	0.27
Maintenance and Servicing	2.55	5.09
Mockups	0.06	0.11
Ground Operations	3.35	6.69
Flight Operations	4.19	8.38
Recovery (End-of-Life Disposal)	TBD	TBD
Program Management	1.50	3.00
TOTALS	31.51	62.99

4.4 PROGRAM PLAN

The LSRF program plan encompasses an approach consistent with the Space Station phasing to accomplish the requirements definition, design, development, assembly, verification, integration, and all aspects of mission support. The plan includes science management, development and implementation engineering, LSRF operation and mission planning, equipment changeout, and resupply and training. LSRF project schedules in the plan are phased with the overall SS schedule and show that the Life Sciences activities must begin close to and be integrated with the Space Station phase C/D program.